

# Data Transport in a Novel Wireless Sensor Network

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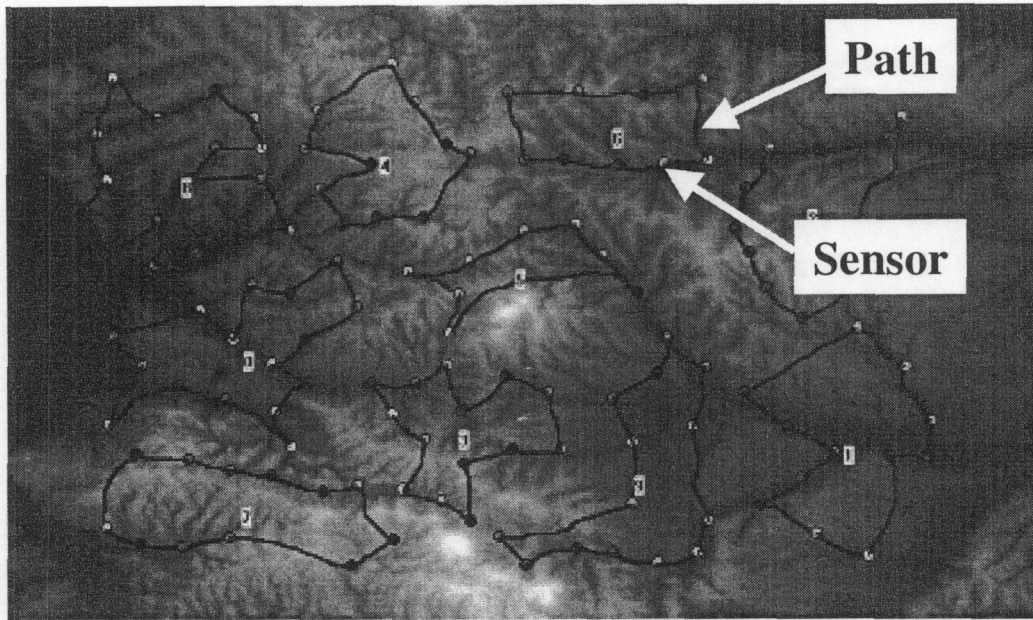
## **Abstract**

The deployment and operation of large wireless sensor networks can pose difficult problems, particularly in time critical situations, over large geographic areas, or in rugged terrain. An approach to this problem is to use unmanned air vehicles to first deploy the sensors, and then provide communication services to the sensors. This paper presents a network model that describes the flow of data through such a sensor network. Simulation results are presented that illustrate the behavior of the data flow in steady state and transient conditions.

## **Summary**

Large networks of land-based sensors are becoming increasingly important for sensing natural and man-made signals. The deployment and operation of large wireless sensor networks can pose difficult problems, particularly in time critical situations, over large geographic areas, or in rugged terrain. As an example, consider the deployment and operation of a sensor network in mountainous terrain. The difficulties associated with hand emplacing such a network are self-evident, and the operation of the network can be troublesome. With regards to operating the network, many sensors employ communications paradigms that require near line-of-sight to establish connectivity between sensors. The use of these sensors in rugged terrain requires a great deal of additional equipment and planning. In particular, repeaters positioned at appropriate locations in the network would be required to provide network connectivity.

An approach to this problem under development at the Lawrence Livermore National Laboratory is to use cooperating Unmanned Air Vehicles (UAVs) to deploy the sensors and then provide communication services to the sensors [1]. In this approach, a group of UAVs deploy sensors over a region of interest and then logically partition the sensors into sub-networks (subnets), with one



**Figure 1: Illustration of a sensor network containing 124 sensor serviced by 10 UAVs. The dots indicate the locations of the sensors on the digital terrain image, and the dark lines indicate the paths followed by the UAVs to service the sensors. The lighter areas of the terrain map indicate peaks, while the darker areas indicate valleys.**

UAV assigned to each subnet. Partitioning the network into subnets allows UAVs to provide communication services to the sensors in parallel while minimizing interference or duplication of effort. An example of network partitioning and subnet formation is illustrated in Figure 1.

The communication service provided by the UAVs to the sensors is a store-and-forward service. Under steady state conditions, each UAV orbits a subnet of sensors along a route connecting all sensors in the subnet. Periodically, a UAV passes over each sensor in its subnet. As the UAV passes overhead, a communication link is established between the UAV and the sensor, and data exchange ensues. At the end of the data exchange, the communication link is released, and the UAV moves on. Data collected from the sensor is stored on the UAV until it has an opportunity to pass the data to a ground station, or to another UAV, which in turn forwards the data to a ground station. When the network operates in steady state, data flows from sensors to ground stations in a periodic fashion. However, in transient conditions (brought about by the network adapting to the addition or loss of UAVs, or the addition or loss of sensors, cf. [1]) data flow is much less predictable.

The transport of data through the network can be modeled by the multiple-input multiple-output system:

$$x_{k+1} = Ax_k + Gw_k + Lu_k$$

where  $\mathbf{x}$  is the system state vector,  $\mathbf{u}$  is an input signal vector, and  $\mathbf{w}$  is a random disturbance vector. The matrices  $\mathbf{A}$ ,  $\mathbf{G}$  and  $\mathbf{L}$  arise in the formulation of the system model. In this model, the state of the system is given by the positions and velocities of each UAV and sensor in the network. The inputs to the system are control signals that adjust the velocities of UAVs in the network, thereby allowing the UAVs to follow paths through their subnets. The output of the system is given by:

$$\mathbf{y}_k = f(\mathbf{x}_k) + \mathbf{E}\mathbf{v}_k$$

where output  $\mathbf{y}$  is a vector-valued time series indicating available communication periods between network elements, and  $\mathbf{v}$  is a vector of random disturbances. Function  $f(\cdot)$  is a nonlinear function that indicates the likeliness of communication between network elements based on the distance between the elements and other factors. Using these equations, data flow through the network can be describe in both steady state and transient conditions.

The full paper describes the sensor network in detail and provides a complete derivation of the data transport model. In addition, simulations are provided that illustrate data flow through the network in both steady state and transient (i.e., during network adaptation) conditions.

#### **References:**

[1] C. T. Cunningham and R. S. Roberts, "An adaptive path planning algorithm for cooperating unmanned air vehicles," *Proceedings of the IEEE International Conference on Robotics and Automation*, Seoul Korea, May 21-26, 2001.